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Surveys in Inclined Shafts: Theoretical and Practical Considerations Governing the Choice of Instruments

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SURVEYS IN INCLINED SHAFTS.

Theoretical and Practical Considerations Governing the Choice of Instruments.

Written for Mines and Minerals, by Joseph Barrell, E. M., M. S.

Mr. Abbe's letter, given in the correspondence column of the March issue of Mines and Minerals, deals with two questions—the use of a side telescope and the means of checking surveys made with it in inclined shafts not connected with other workings. In answering these it may be well to enlarge the discussion, in order to embrace any style of instrument and to show the theoretical and practical advantages pertaining to each. The theoretical conclusions seem clear enough, but since it has never been the writer's fortune to use a side telescope, there may be practical considerations governing work with them which have escaped him.

In the issue of Mines and Minerals of May, 1899, the theory of errors upon highly-inclined sights was considered and the applications made to a survey by an instrument with inclined or eccentric standards. It was made evident that for very steep angles errors of considerable magnitude were liable to occur, and it was the necessity of eliminating these which compelled the working out and application of the method there given. To reduce the subject to the limits of a single article, briefness was necessary, and the present discussion is an amplification of the topics touched upon on page 435, last column. The figures and demonstrations showing the way and the amount in which the errors of adjustments affect steep angles, have been given in the article alluded to. It will be unnecessary to repeat that work, and, consequently, one wishing to work out the subject fully will find it necessary to refer back to it.

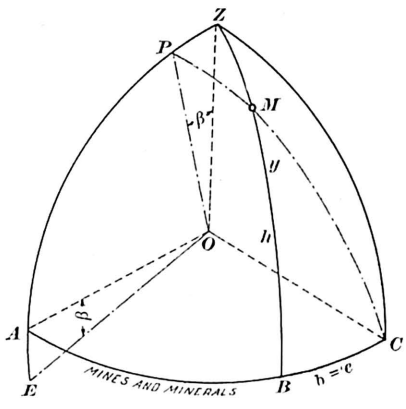

Fig. 4 From Page 435 Mines and Minerals, May, 1899.

Before passing on to our present topic it may be well to state, however, for the benefit of any who may wish to look the subject up, that the effect of a change in adjustment or a reversal of the telescope is made most evident by redrawing the figures there given to meet the new conditions. For instance, to observe the way in which lack of level in telescope axis affects results, take Fig. 4. OM is the line of sight, OE is the prolongation of the axis passing through the standards, and it is seen that the *right* one has been taken as being *low*. Upon reversal of the telescope and repeating the sight the *right* standard will then be *high*. To redraw the figure for this condition, OE, the horizontal axis, will be inclined above OA. P and M are thrown beyond ZC. The error being measured from the meredian, ZC is now in the opposite direction, and, consequently, of the opposite sign, showing that the mean of two such sights eliminates the error.

The Three Classes of Errors.—Before passing to a consideration of the best types of instruments for various kinds of work it will be well, in order to gain an intelligent view of the subject, to glance for a moment at the kinds of error which may affect the azimuth, or horizontal angles, not considering those which can be eliminated by repeating the angle.

The *first* class embraces the errors due to imperfect leveling of vernier plates, lack of adjustments of standards, and the collimation line. Their common feature is that their effect upon the work is independent of the linear distance, depending upon the vertical angle only, and, in a well-adjusted instrument, only becomes appreciable when the latter is very high.

The *second* class is represented by the eccentricity of the collimation line. This is the amount by which, after being adjusted for its angular error, it passes to one side of the center of the instrument. In the side telescope attachment the eccentricity is several inches. This class differs from the first in that the effect upon the results is independent of the vertical angle, depending on the contrary upon the *horizontal* distance, becoming larger when the latter is small.

In practical use in difficult work these are the only two which the writer found it necessary to consider.

There is a *third* and final class, however, whose occurrence is not at all impossible, that depending for its effect upon both the vertical angle and linear distance. This results from imperfections in the telescope, the optic axis slightly changing in direction in focusing for short sights, thereby bringing in distance as an element determining the size of the collimation error.

An instrument may be tested once for all for this error in the following manner, and it seems unnecessary to go further than that into this question. Set up in some convenient place and locate a series of common pins precisely in line, at distances of about 6, 12, 30, 50, 70, 88, and 94 feet from the instrument, by merely changing the focus and moving the telescope the necessary amount vertically. Now set up about 6 feet beyond the last pin and cut into line with the pins 30, 50, and 70 feet away, as in shaft plumbing. Having gotten precisely in line, the nearest and farthest pins should also be bisected by the cross-hairs upon changing the focus. If such is not the case half the angular divergence is the *change in collimation* error due to focusing, but not the full collimation error.

The Three Types of Instruments.—The instruments designed for sighting at high vertical angles are of many makes, but may all be classed under three principles: those with eccentric bearings for the main telescope, those with auxiliary top telescope, and those with auxiliary side telescope. It is our next duty to see to what degree these, from their nature, reduce or eliminate the several classes of errors.

The instrument with *eccentric standards* one of which was illustrated in the May article, must be used with telescope normal for sighting downward at steep angles, and with telescope reversed for similar upward sights. The *top telescope* can only be used with telescope normal for all angles. With the side telescope it is, of course, necessary to take readings to every point with telescope first normal and then reversed, in order that the true angle shall be obtained from the mean. This clearly eliminates the gross error due to the use of the side telescope, but it remains to be seen in what degree it effects the small errors common to all instruments.

Effect of Imperfect Leveling of Vernier Plate.—If the vernier plate is not precisely leveled the axis of the spindles is not truly vertical, and its position will not be altered during the set up by any manipulation of the telescope. Consequently, its effects must be eliminated from the work of every class of instrument. It cannot be estimated and allowed for subsequently but must be avoided by the use of at least one sensitive plate bubble. By using great care for higher angles results correct to the minute may be obtained for angles up to 88°. The horizontality of the plate is determined during the set up in the manner described on page 434, May, 1899. The sensitiveness of the bubbles may be tested by throwing the instrument decidedly out of level and then leveling up again. If upon renewed sights after releveling the *horizontal* angles read precisely as before, it is evidence that for such *vertical* angles the bubbles are sufficiently sensitive.

Effects of Other Errors.—With the inclined standard instrument nothing can be done at each set up to eliminate the small errors further than repeating the sights and doubling the angle, avoiding in that way accidental errors of sighting and reading. Since the position of the telescope cannot be reversed upon repeating the sight, none of the classes of errors enumerated can be avoided. Where a number of set ups are necessary to carry a line down an incline, it is the errors due to collimation and eccentricity of telescope which accumulate, the others somewhat balancing. With long sights the eccentricity of telescope error will become insignificant.

In the use of the top telescope the same statements may be made as with the inclined standard instrument, except that it is the error due to imperfect adjustment of the standard, which keeps accumulating with repeated set ups.

With the side telescope *all errors*, except those due to imperfect leveling of the vernier plate, are eliminated from *each* set up, and this is a very noteworthy feature.

In the foregoing the adjustment of the vertical circle has not been mentioned, since the vertical angle and distance can always be checked by measuring them on both foresight and backsight.

Practical Considerations.—The writer is by no means prepared to settle the question as to which style of instrument best combines rapidity, ease, and accuracy under all conditions. Actual use must always supplement theory before a final verdict can be reached. The most obvious advantages of the several types can, however, be readily summed up.

For mine work where fairly frequent highly-inclined sights are necessary, the instrument with eccentric standards is the simplest, requiring no auxiliary telescope with its extra adjustments. All linear measurements should be made from the horizontal axis of revolution of the telescope. This avoids the necessity of correcting the vertical angles on account of the eccentricity of the telescope axis, the latter being allowed for in the office by adding or subtracting the amount of the eccentricity in hundredths of a foot to every reduced horizontal distance. The same telescope being used for all work, its adjustments are presumably in

better shape than in an auxiliary telescope, and will be sooner detected if they are not. The writer has used such an instrument for all classes of work and found it as convenient as the regular style. Consequently he can see no advantage to offset the weight and expense in an instrument having *two* sets of bearings, one normal and one eccentric, into the latter of which the telescope must be transferred for steep sights.

The advantage of the top telescope attachment to the common style of transit is chiefly in the lesser price of the combination compared to that of the instrument with eccentric standards. Its disadvantage, as compared to the latter, lies in the extra telescope necessary and also to the fact that the level bubbles of the common styles do not have the sensitiveness desirable for sighting on high angles.

The use of the side telescope, as we have seen, eliminates all instrumental errors except that due to non-horizontality of the vernier plate. Thus the necessity of sensitive bubbles is seen to be quite irrespective of the style of instrument. The great advantage of the side telescope is that by exercising care the work corrects itself under all conditions, and if it is an important piece of work the engineer does not have to do some hard thinking in the office to be sure that he has eliminated the effects of instrumental errors. The objections to its use are in its exposed position, and the fact that at every set up twice the usual number of readings must be taken, whether or not the character of the work demands it.

In using the first two types, a sensitive instrument in *good* adjustment should not give readings a minute out for vertical angles of 75° or less, but for greater angles, especially over 80°, errors should always be guarded against by suspending a wire as suggested in the May, 1899, issue of Mines and Minerals, setting the instrument close to it and with a constant backsight sighting to points on the wire at all vertical angles. All of them should give the same horizontal readings. In using a side telescope, theoretically, no such errors should appear at any angles.

From this discussion it would seem to the writer that the best practical mining transit is the usual style, provided with sensitive bubbles, and with auxiliary telescope, attachable to either top or side. Such an instrument, made by Berger & Sons, of Boston, is shown in the illustration. For unimportant work it would be attached to the top, saving the extra sights; for important work to the side. If such should come to be recognized, no doubt the attachment at the end of the axis could be made more elaborate, if necessary, as corresponding with its importance. Or, if other reasons appealed more strongly, an instrument with eccentric bearings could be chosen, such as was illustrated in the May, 1899, issue of Mines and Minerals.

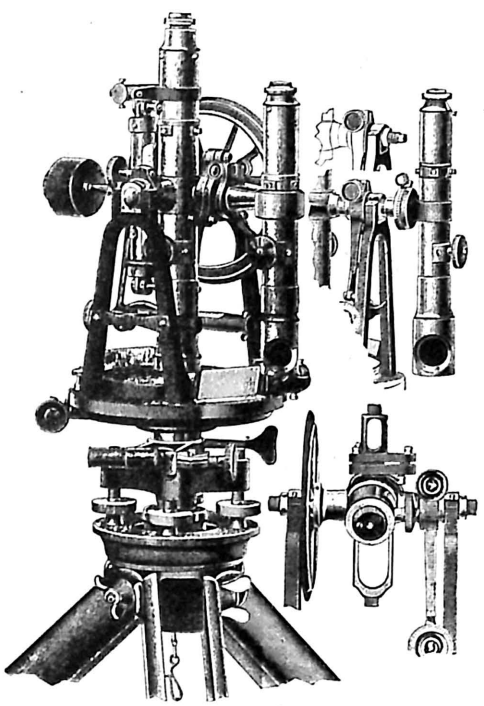

Fig. 1. Berger & Sons Mining Transit.

Closing the Survey Within the Shaft.—Mr. Abbe's idea of taking double backsights, by which he made a closed survey of three sights within the shaft, is one worth discussing in order to show when it is of value in checking the work of the instrument. In the previous article, page 435, May, 1899, issue of Mines and Minerals, it was shown that where a number of sights are necessary to carry a survey down a steep incline, that certain errors are more or less completely eliminated, whereas others keep accumulating.

With a top telescope the error of standards, being that due to lack of horizontality in the telescope bearings, is the one occurring with accumulative effect, while for an instrument with eccentric bearings it is the collimation. To find the amount of this accumulating error, and to guard against it, we may proceed as follows: Fig. 2 represents diagrammatically the survey lines in a shaft with five levels, *0* being at the surface, the other stations on the hanging wall-plate at each level. From *0* sight to each level. Then set up at (*1*), backsight to (*0*), foresight into the cross-cut and also down the shaft to (*2*). Set up at (*2*), backsight to both (*1*) and (*0*), and foresight both into the cross-cut and to (*3*). The bearings of each level are obtained by the direct sight to the surface. The sights to the two adjacent levels are to make the closed survey. In the final close, *0, 1, 2, 3, 4, 5, 0*, there are five downward courses and one upward, and the error of closure is the accumulated error of four courses. Since the bearings are brought to each level by one course, each level can be corrected by one-fourth this total amount. The propriety of ascribing all the error of closure to a progressive error can be tested by seeing if the close made at each level grows greater according to the number of set ups from the surface.

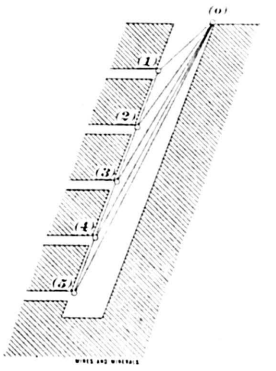

Fig. 2.

Such a method furnishes no information as to errors produced by imperfect leveling, and since that is the one remaining to be guarded against in the use of a side telescope, the method is of no value for that instrument.

The great advantage of the method for the other two classes of instruments is that it measures only the error which affects the work and does not bother about the others. The only practical difficulty of carrying it out is in the inconvenience of having a man at the surface, another at the level above, and a third at the level below, to give the sights when needed, and the time consumed in taking them. It would presumably be quicker to test the instrument by sighting to various points on a wire.

Conclusion.—The writer does not imagine that all these "errors" will have to be looked after in every survey. It was an unusual problem in surveying which called his attention to the subject, though many engineers have been bothered in getting accurate results at high angles. It will be comparatively seldom that a table of corrections will have to be applied to the work, and whatever value these articles may have lies chiefly in showing what is to be guarded against, the particular adjustments which affect the several types of instruments in shaft or raise work, the relative advantages of instruments for such cases, and ways of testing the work when it is desirable to do so.